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(54) Regenerative power system

(57) A regenerative-type hybrid power system A regenerative-type hybrid power system (20), according to the present invention, comprises a first car (30) having a load (13) that comprises an electric load for driving; an electric power generation device (40, 4, 5) comprising at least one of electric power supply devices among a first electric power supply device (40) which is provided on the first car to generate electric power, second electric power supply devices (5) which are provided on the ground to generate electric power and transmit and transform the generated power, and third electric power supply devices (4) which are provided on other cars to supply electric power to the outside that is surplus;a regenerative fuel cell (7), for storing the chemical energy by utilizing the electric power that is supplied from the electric power generation device and regenerating the stored chemical energy, which comprises a water electrolysis device (9), a storage device (10) for storing up at least the electrolyzed hydrogen and the oxygen, a fuel cell (11) for generating electricity using the stored hydrogen and oxygen as fuel, and a heat exchanger (8) for the water electrolysis device, the storage device and the fuel cell; a regenerative control device (12) for controlling regeneration of the electric power by the regenerative fuel cell (7) to supplement lack of the electric power that is supplied to the load (13). The hybrid power system of this invention can realize a high speed energy conversion and storage system as well as a high power generation system to maintain high energy weight and volume efficiency, the purpose of this invention, the high speed energy conversion and storage and the high power generation of electricity, can be realized in a form to maintain high energy weight and volume efficiency.

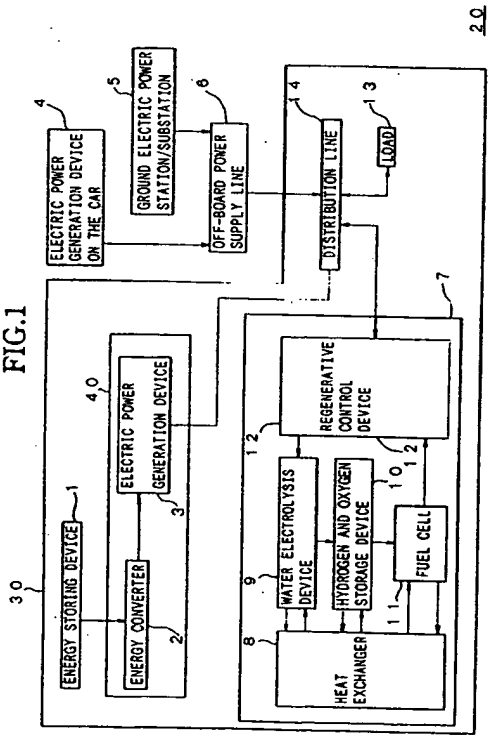

FIG.1

EP 0 755 088 A2

fuel cell system (International Hydrogen and Clean Energy Symposium sponsored by NEDO, 1995, pp. 31); but it is used only for storing and regenerating energy and it does not have a purpose of sustenance of required power of a high rank order by means of energy storing of surplus power and energy discharging in a maximum efficiency operation utilizing all the ability of power generation. There is also a pumped-storage power station as another regenerative-type power generation system (The Journal of the Institute of Electrical Engineers of Japan, Vol. 115-B, 6, 1995, pp. 447). The location of the pumped-storage power station is generally remote from the place of demand. Therefore, that system has a problem that power transmission loss is inevitable.

In addition, there is a system employing a governor, etc., to adjust a supply and demand balance which is influenced by a change of the electric power load and the change of generation power due to an extraordinary parallel off of an electric power generation device, etc., but there is still a problem that an adjustment speed is not always as fast as is expected in conventional electric power systems.

Summary of the Invention

It is an object of the present invention to solve the above-mentioned problems by realizing a speedy energy conversion and storage system in a high power generation system to maintain high energy to weight and volume efficiency.

According to the present invention, a regenerative-type hybrid power system is provided, which is composed of an electric power generation and supply device for generating electric power and supplying an electric power system with the electric power; a regenerative fuel cell for storing a chemical energy by utilizing the electric power which is supplied from the electric power generation and supply device and for regenerating the electric power by utilizing the stored chemical energy, which comprises a water electrolysis device that electrolyzes water, a storage device that stores up at least the hydrogen between the electrolyzed hydrogen and oxygen, a fuel cell that uses the hydrogen which is stored in the storage device and oxygen as fuel and generates electricity, and a heat exchanger which exchanges the heat of the water electrolysis device, the storage device, the fuel cell, and atmosphere; a load for receiving electric power from the electric power generation and supply device and regenerative fuel cell; a regenerative control device which compares a supply and demand difference between the generated electric power of the electric power generation and supply device and the electric power which the load receives. The device that electrolyzes water, a storage device which stores up at least the hydrogen of the electrolyzed hydrogen and oxygen, a fuel cell that generates electricity using the hydrogen that is stored by the storage device and oxygen as fuel, and a heat exchanger that exchanges the heat of the water-electrolysis device, the storage device, the fuel cell, and atmosphere; a regenerative control device for controlling regeneration of the electric power from the regenerative fuel cell to supplement the lack of the electric power that is supplied to the load.

Another aspect of the present invention is a regenerative-type hybrid power system which comprises a fuel cell which comprises a water electrolyzer which electrolyze water to produce hydrogen and oxygen, and a storage device for storing at least hydrogen produced by the water electrolyzer; a load for driving a car and producing regenerative braking power; a foreign power supply system which is not included in a predetermined area which is determined by a contract between a power supplier and a demand user; a off-board power supply system, such as an overhead contact line, which exists in the predetermined area outside the car; wherein, when the regenerative hybrid system has a economical advantages under the conditions that receiving power from the power supplier has a room enough to supply power in a contract demand between the demand user and the power supplier with high penalty charge in the case of regenerative control device operates the water electrolysis device with the surplus power of the generated electric power according to necessity; stores up at least the electrolyzed hydrogen when generated electric power is a supply surplus; and controls the excess and surplus of the electric power, which occurs in the electric power system, by regenerating electric power by means of the fuel cell with the stored hydrogen and oxygen when the generated electric power is lacking.

Another aspect of the present invention is a regenerative-type hybrid power system which comprises a first car which has a load that comprises an electric load for driving, air conditioner, light, etc. (as in all following examples); an electric power generation device comprising at least one of electric power supply devices among a first electric power supply device which is provided on the first car and generates electric power, second electric power supply devices which are provided on the ground and generate electric power and transmit and transform the generated power, and third electric power supply devices which are provided on other cars that are different from the first car and supply to the outside electric power that is surplus; a regenerative fuel cell for storing a chemical energy by utilizing the electric power that is supplied from the electric power generation device and for regenerating the stored electric power, which comprises a water electrolysis receiving power over the contract demand, and a regenerative braking power has a room enough to supply power over to the extent to which the foreign power supply system can absorb the feedback of the braking energy to the off-board power supply system, the regenerative hybrid system operates the water electrolyzer storing up at least the hydrogen and oxygen to the storage device, on the other hand, when the foreign power except the system falls

generative control device 12 also controls each device so as to control water electrolysis device 9 to electrolyze the stored water by supplying electric power from off-board power supply line 6 to water electrolysis device 9 through distribution line 14 on the car when there is a surplus (room) of electric power in the electric power on the power supply side as seen from off-board power supply line 6. Regenerative control device 12, then controls hydrogen and oxygen storage device 10 to store the hydrogen and oxygen which are generated.

If there is surplus electric power on the power supply side as seen from off-board power supply line 6 when regenerative braking is activated at load 13, regenerative control device 12 also controls each device in order for water electrolysis device 9 to electrolyze the stored water by supplying electric power from load 13 in regenerative braking condition to water electrolysis device 9 through distribution line 14 on the car and it controls hydrogen and oxygen storage device 10 to store the hydrogen and oxygen which are generated. The preferred embodiment which is shown in FIG. 1 can be thought of as a system of self-excitation on a car because it is equipped with one of the electric power supply sources for load 13 on car 30. That is, the hybrid power system in FIG. 1 includes electric power generation device 40 on the car as well as electric power generation devices on the ground and regenerative fuel cell 7. Moreover, it can be thought of as a system of self-excitation and regeneration on the car because regenerative fuel cell 7 for regenerating electric power is also installed on car 30.

As a modification of the preferred embodiment shown in FIG. 1, in case of omitting energy converter 2, such as a combustion engine, etc., which indirectly converts the electric energy, configuration of electric power generation device 40 may be changed to modify the generation system between energy storing device 1 and electric power generation device 3 to directly connect energy storing device 1 and electric power generation device 3. It is also possible to think that load 13 includes not only the loads which are installed on car 30 but also includes loads outside on other cars. A device for acquiring atmospheric air (oxygen) may be employed instead of the device for storing only oxygen in hydrogen and oxygen storage device 10. Furthermore, these modifications can be applied in the same way to the preferred embodiments which are described below.

Next, another preferred embodiment of a hybrid power system according to the present invention is explained using FIG. 2. FIG. 2 shows a composition of a hybrid power system consisting of off-board power supply systems (external-excitation systems) as contact systems, and on-board power supply systems (regeneration systems on a car). In addition, in FIG. 2, identical reference numerals are attached to the components which are identical with those in FIG. 1 (as in all following examples).

Hybrid power system 21 which is shown in this figure is composed of an electric power generation device 4 such as a regenerative apparatus, which is located on a car, ground electric power station/substation 5, and off-board power supply line 6, all of which exist outside car 30a; and regenerative fuel cell 7, load 13 as a driving apparatus, and distribution line 14, which is located on a car, all of which are installed in car 30a. In this preferred embodiment, all the electric power which is supplied to regenerative fuel cell 7 which is installed in car 30a is supplied from the outside of car 30a as long as generation of electricity by regenerative braking of load 13 is not activated. Regenerative fuel cell 7 is composed of heat exchanger 8, water electrolysis device 9, hydrogen storage device 10, fuel cell 11, and regenerative control device 12 as in FIG. 1. When electric power is determined to be lacking, regenerative control device 12 supplies load 13 with the output of fuel cell 11, as supplement power to supply on-board load from external power (power from electric power generation device 4, etc.), directly, or indirectly after changing the state of the output to an alternating current or a direct current power supply to meet the requirements of load 13, through distribution line 14. On the other hand, when the electric power is determined to be surplus, regenerative control device 12 operates water electrolysis device 9, hydrogen storage device 10, and heat exchanger 8 to store hydrogen.

Next, another preferred embodiment of a hybrid power system according to the present invention is explained referring to FIG. 3. Hybrid power system 23 which is shown in FIG. 3 is a hybrid power system of self-excitation and external excitation, and regeneration on the ground. Hybrid power system 23 is characterized in that the system is equipped with ground substation 5a which is set up on the ground and consists of energy storing device 1; electric power generation device 40 having energy converter 2 and electric power generation device 3; and regenerative fuel cell 7a. On the ground, hybrid power system 23 also has electric power generation device 4 on another car comprising a regenerative apparatus, etc., and ground electric power station/substation 5 as other electric power sources; and also has off-board power supply line 6. Therefore, in this preferred embodiment, only load 13 and distribution line 14 are provided in car 30b and car 30b is not equipped with any device for generating electric power. Electric power for load 13 is supplied through off-board power supply line 6 and distribution line 14, which is on the car, from ground substations 5 and 5a and electric power generation device 4 which is on another car. Regenerative fuel cell 7a is composed of heat exchanger 8, water electrolysis device 9, hydrogen storage device 10, fuel cell 11, all of which are composed like the corresponding components shown in FIG. 1, and regenerative control device 12a. Regenerative control device 12a determines the excess or deficiency condition of electric power and, when lacking, it supplies the electric power that fuel cell 11 generates to load 13, such as a driving de-

ing existing substation capacity by this usage. A higher allowable minimum setting voltage can, therefore, be used when the run curve of the car is determined, and increases in the speed of the car can also be realized.

(2) Prevention of a substation capacity increase and establishment of a new substation for high power trains which run in low frequency in feeder sections that are designed as a railway for a standard train organization, and the effect of preventing the feeder voltage from being less than an allowable minimum voltage

Substation capacity is set to correspond sufficiently to a standard train organization which runs in a feeder section. On the other hand, there are some needs for electric locomotives which have bigger outputs than standard train organizations for high power trains like limited express trains which have relatively longer train organizations, etc., to run in low frequency in the feeder section in which a substation capacity is determined according to a standard train organization. However, in conventional systems, it is not possible to run such irregular train organizations without changing facilities because a lack of a substation capacity, or the occurrence of feeder voltage falling below an allowable minimum voltage due to a voltage drop are always expected. On the other hand, if using a hybrid power system according to the present invention, it is possible to prevent the lack of a substation capacity and the fall of a voltage below the allowable minimum voltage due to a voltage drop, and it is, therefore, possible to avoid a substation capacity increase, and the establishment of a new substation to run high power trains which are use in low frequency.

(3) Reduction effect of capital expenses for new line construction by extending substation interval for trains which run on the new line in a low frequency

By introduction of a hybrid power system of regeneration on a car according to the present invention, it is possible to extend the substation interval because it is possible to generate electricity on a car to supplement the power or the voltage which is lacking in the middle of adjacent substations or at the end section of a one-direction sending substation.

(4) Service improvement effects by avoiding railcar operation in electrified sections or transferring passengers at points between electrified and non-electrified sections

There is an example that a mixed car comprising an electric car and a railcar is used for sections which include both electrified and non-electrified sections in a conventional system. However, if a hybrid power system of on-car-regeneration according to the present invention is introduced, it is possible to organize a train using only electric cars and thereby obtain high serviceability. If the train is equipped with a regenerative fuel cell, it is possible to run the train through non-electrified sections located between electrified sections when the non-electrified sections are relatively short. It is also possible to avoid upgrading of narrow tunnels when electrifying a railroad with frame lines by leaving the tunnel as a non-electrified section and running trains equipped with a regenerative fuel cell in the tunnel. Therefore, the investment effect of electrification improves because expensive tunnel upgrading expenses can be reduced.

(5) Energy saving operation by using deactivated electric power during regenerative braking generation of electricity

Electric power generated by regenerative braking is basically supplied to another car which runs close to the car that generates the power. However, when the regenerative braking power is surplus for the reason that there is no train running nearby, etc., the regenerative braking power is deactivated to prevent a voltage rise in the feeder circuit. On the other hand, it is possible to utilize such deactivated electric power for charging a regenerative fuel cell if a hybrid power system according to the present invention is employed. Therefore, an energy saving effect, a substation capacity reduction effect, a shoe consumption reduction effect, etc., may be expected if a hybrid power system according to the present invention is introduced.

(6) Capital expenses reduction effect by eliminating installation of spare conversion equipment

In conventional systems, spare electric power conversion equipment is required to prevent train operation hindrance in the case of trouble with regularly used conversion equipment. However, a hybrid power system according to the present invention can avoid the installation of spare conversion equipment because a regenerative fuel cell can be used instead of the spare conversion equipment. That is, it is possible to prevent train operation hindrance even if the regularly used conversion equipment causes trouble and the above-described capital expenses reduction effect may be expected.

In addition to the above-mentioned possibilities, there are some other possibilities as follows. A fixed minimum charge for a power company is determined by a measured demand peak value. Therefore, an effect of a reduction in expenses cut effect may be expected because reduction in the peak value may be possible with a hybrid power system that has multiple supplies on a car and on the ground. When attempting stable electric power transmission in an electric power system, there are some criteria to be secured with regard to voltage stability as well as steady-state stability and transition stability for electric power. In the past, for electric power stability, stabilization of electric power is attempted by controlling the reactive power of lead and lag by means

generation of electric power by said regenerative fuel cell to supplement lack of the electric power that is supplied to said load.

3. A regenerative-type hybrid power system according to claim 2, wherein said regenerative control means controls regeneration of the electric power to supplement the lack of the electric power by

operating said water electrolysis device and storing up at least the hydrogen between the generated hydrogen and oxygen to said storage device according to demand, if one among the electric power that is supplied from said electric power generation means, the electric power that is regenerated by said electric load for driving, and the sum of both electric power exceeds electric power consumed by said load when electric power is regenerated by said electric load for driving, and

operating said fuel cell with the hydrogen stored up and oxygen according to demand after making a predetermined economical decision in electric fee system, when the electric power that is supplied from said electric power generation means falls below the electric power consumed by said load.

4. A regenerative-type hybrid power system defined in one of claims 1, 2, and 3, wherein said electric power generation means includes at least said second electric power supply device; and the second electric power supply device and said first car comprise said regenerative fuel cells, respectively; and said regenerative control means control regeneration of the electric power that both the fuel cells regenerate, which said second electric power supply device and said first car comprise, by linkage operation according to demand.

5. A regenerative-type hybrid power system defined in one of claims 1, 2, and 3, wherein said electric power generation means includes at least said second electric power supply device; and the second electric power supply device and said first car comprise said regenerative fuel cells, respectively; and said regenerative control means control regeneration of the electric power that the fuel cells regenerate, which said second electric power supply device and said first car comprise, according to a demand to maintain a maximum efficiency operation of regeneration in both the fuel cells by linkage operation.

6. A regenerative-type hybrid power system, comprising:

a fuel cell which comprises a water electrolyzer which electrolyze water to produce hydrogen and oxygen, and a storage device for storing at least hydrogen produced by the water electrolyzer;

a load for driving a car and producing regenerative braking power;

a foreign power supply system which is not included in a predetermined area which is determined by a contract between a power supplier and a demand user;

a off-board power supply system, such as an overhead contact line, which exists in the predetermined area outside the car;

wherein, when the regenerative hybrid system has a economical advantages under the conditions that receiving power from the power supplier has a room enough to supply power in a contract demand between the demand user and the power supplier with high penalty charge in the case of receiving power over the contract demand, and a regenerative braking power has a room enough to supply power over to the extent to which the foreign power supply system can absorb the feedback of the braking energy to the off-board power supply system, the regenerative hybrid system operates said water electrolyzer storing up at least the hydrogen and oxygen to said storage device, on the other hand, when the foreign power except the system falls below the electric power consumed by said load, the system operates fuel cell with hydrogen stored up and oxygen or air, and supplement the lacking power to the load through off board power supply line.

FIG.2

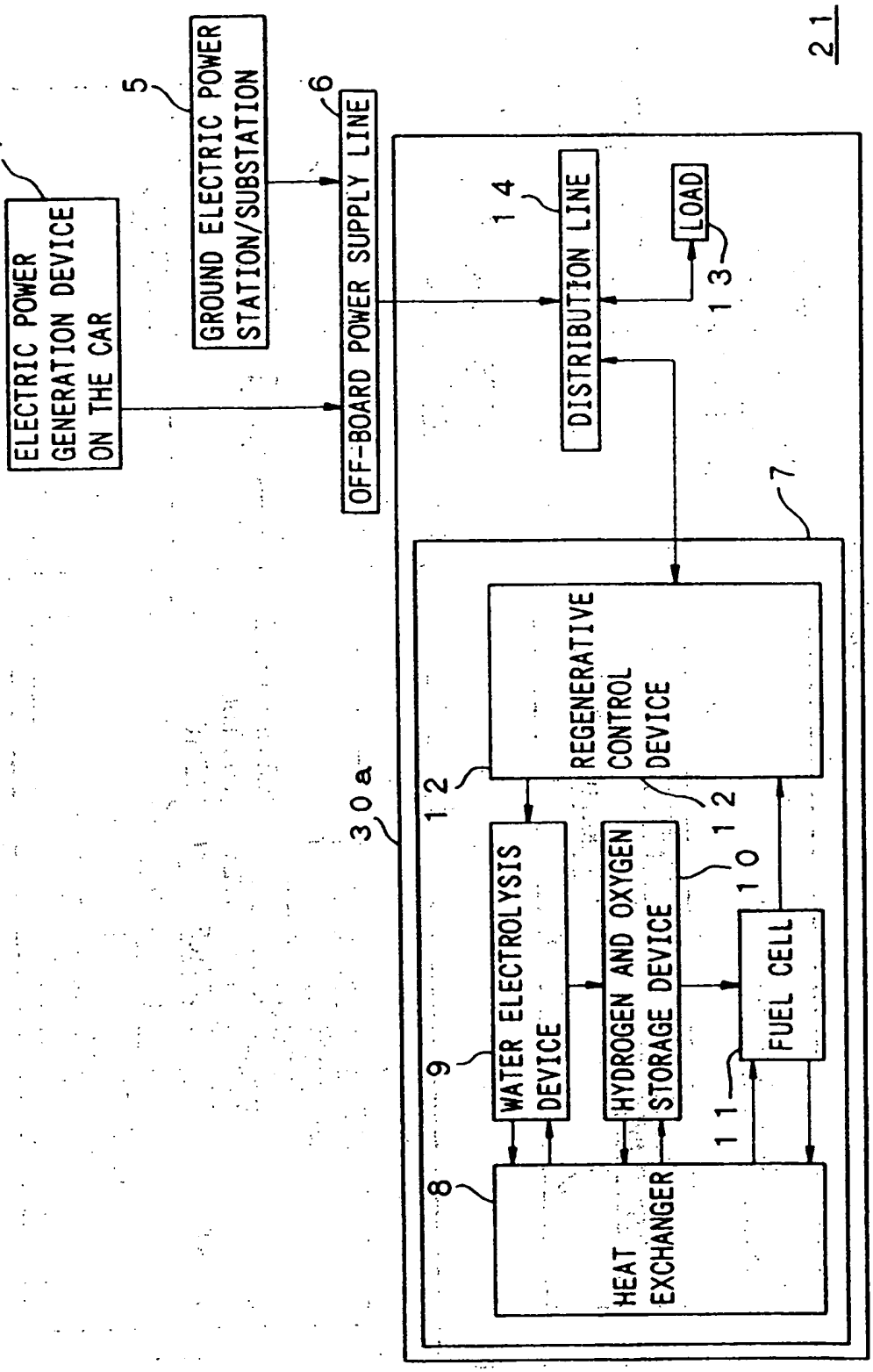
21
4
ELECTRIC POWER GENERATION DEVICE ON THE CAR
5
GROUND ELECTRIC POWER STATION/SUBSTATION
6
OFF-BOARD POWER SUPPLY LINE
14
DISTRIBUTION LINE
LOAD
13
7
30a
12
REGENERATIVE CONTROL DEVICE
12
9
WATER ELECTROLYSIS DEVICE
10
HYDROGEN AND OXYGEN STORAGE DEVICE
11
FUEL CELL
8
HEAT EXCHANGER

FIG.4

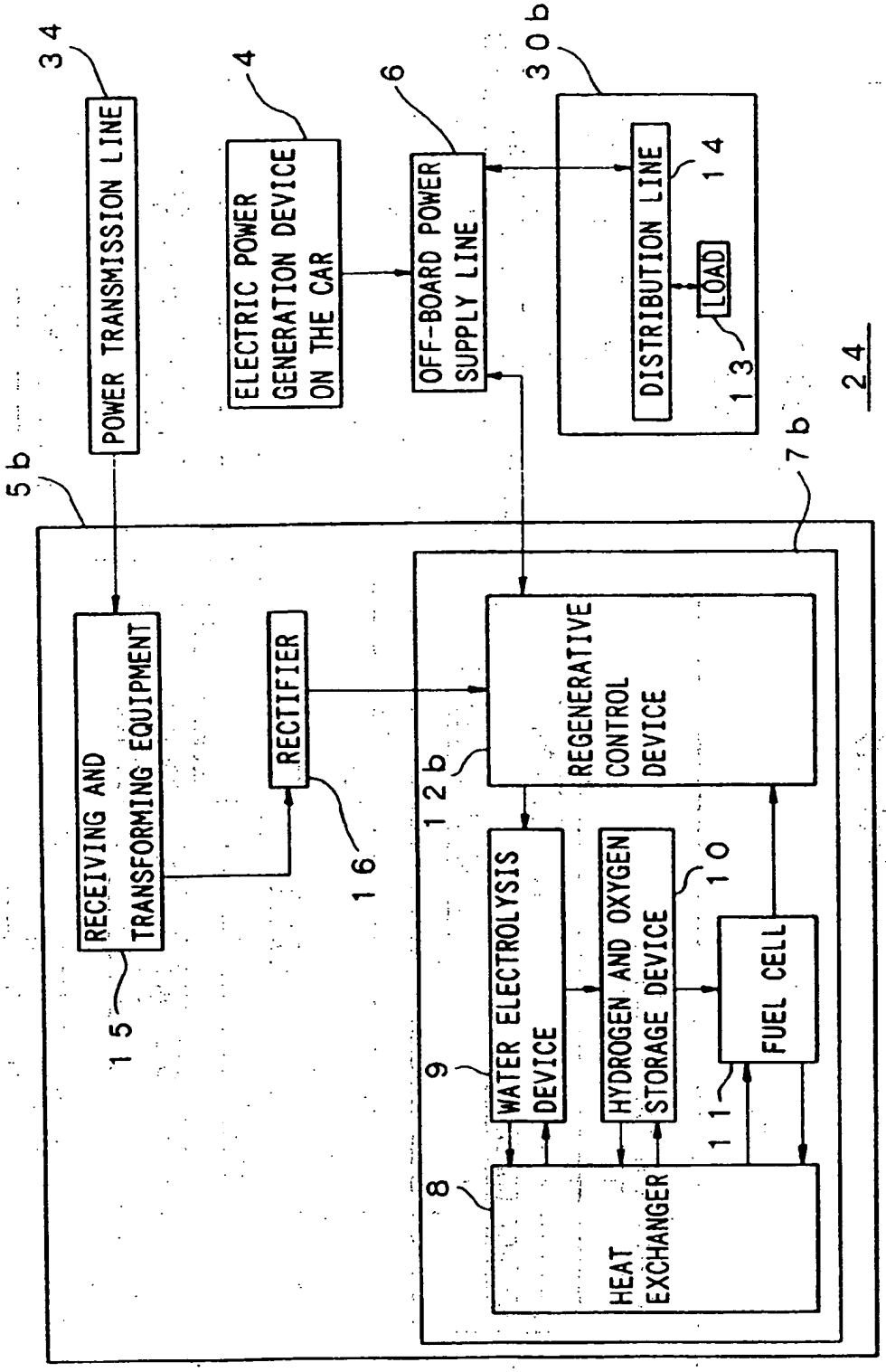
34
POWER TRANSMISSION LINE
4
ELECTRIC POWER GENERATION DEVICE ON THE CAR
6
OFF-BOARD POWER SUPPLY LINE
30b
DISTRIBUTION LINE
14
LOAD
13
24
5b
7b
RECEIVING AND TRANSFORMING EQUIPMENT
15
RECTIFIER
16
REGENERATIVE CONTROL DEVICE
12b
WATER ELECTROLYSIS DEVICE
9
HYDROGEN AND OXYGEN STORAGE DEVICE
10
FUEL CELL
11
HEAT EXCHANGER
8

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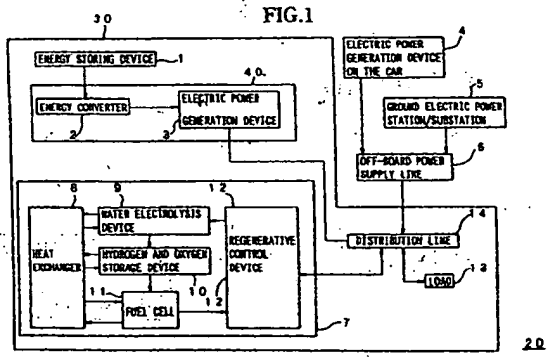
FIG.1



EP 0 755 088 A3